Lately conventional agricultural systems have increased their dependence upon external inputs, mainly on fertilizers and pesticides. The increased dependence constitute a challenge to the long-term productivity and sustainability of non-food crop and/or food crop systems because of environmental and logistics constrains. The importance of crop rotation, however, has been long recognized as an alternative system that can reduce agriculture’s dependence on external inputs through internal nutrient recycling, maintenance of the long-term productivity of the land, avoidance of accumulation of diseases and pests associated with mono-cropping, and increased crop yields, (Gebremedhin and Schwab, 1998; Peel, 1998; Krupinsky et al., 2002). Crop rotation also can help to reduce soil erosion, improve soil structure, enhance permeability, increase biological activity, increase water and nutrient storage capacity, and increase the amount of organic matter in soils (Gebremedhin and Schwab, 1998; Peel, 1998).

The aforementioned beneficial effects can be further improved by combining crop rotations with cover crops and reduced or no-tillage practices (Gebremedhin and Schwab, 1998; Peel, 1998; Zenter et al., 2002). Moreover, combining crop rotation and pesticides is an effective way of reducing pest populations. Fallowing is also used in combination with rotation systems to enhance their beneficial effects, especially in dryland areas where there are few alternative crops to choose (Gebremedhin and Schwab, 1998). However, barriers that would stop farmers for adopting crop rotation systems are the need for diversified farm activities, and information, as well as more diversified equipments and storage facilities. Also because the management skills and required knowledge are higher (Ikerd, 1991; Peel, 1998). These barriers may be even more prominent in the case of new promising non-food energy crops.

Crop rotations are characterized by growing a wide variety of crops in a sequential system on a given cultivated land and by the associated management practices. Rotation plans are usually built around one or two leading crops, followed by one or more legumes and/or
other crops. It is important, however, to include legumes in the rotation as they fix nitrogen, contribute to soil structure, to erosion control, to forage production, and cash hay and seed production.

Although various cropping systems can be technically feasible, there is no one right rotation system and a decision criteria is required to chose the best one that would fit to the specific conditions of a site [e.g. soil quality and fertility, environmental characteristics and/or profitability (Gebremedhin and Schwab, 1998; Peel, 1998)]. Therefore, rotation systems should be tailored to suit a particular farm or group of farms, and that involves many variables. For example, from the biological point of view the sequence of crops in rotation affect the availability and use of water and nutrients and consequently, crop yields. Therefore the criteria for selecting a crop rotation system could be based on the optimization of the use of such soil resources that usually are the two most limiting factors for crop production. In that case, crops that deplete soil resources should be alternated with crops that replenish, to some extent, soil resources.

Rooting depth and time to maturity are also important factors that should be considered when planning a sequence of crops in rotation. Deep rooted crops are best fitted to follow shallow rooted crops because the deep rooted crops can use the water and nutrients that moved to deep soil layers during the previous season, as in the case of small grain crops and sunflower or sorghum rotations. Medium or deep rooted crops appear to be better adapted to follow shallow rooted crops (Peel, 1998).

Other criteria to take in consideration when planning crop rotation systems are the environmental and economic conditions. Among the environmental factors, the climate and type of soils play an important role when choosing the species to be included in the rotation. The prevailing economic situation, availability of agricultural equipment, availability of economic resource, markets and laws are also important factors to consider when planning a rotation system.

When planning crop rotation systems, the current climate change scenario has to be considered too. As climate change will have an impact on land use and vegetation cover, it is predicted that the potential distribution of temperate oilseed, cereals, starch and solid biofuels will increase towards northern Europe by the 2080s, due to increasing in temperatures, and will decrease in southern Europe due to increasing drought (Tuck, et al., 2006). Therefore the tailored rotation systems for energy crops will have to adjust to the changing conditions and evolve continuously. For example, in the future hemp may not be appropriate in any rotation
system in southern Europe as this crop is predicted to disappear from the region by 2080 (Tuck, et al., 2006). On the other hand, rotations with oilseeds, cereals, starch crops and biofuel crops could be intensified in northern Europe as they potentially will be more widely spread in this region.

In some cases, traditional food crops are used as dedicated crops with the advantage that they fit well into conventional crop rotations. This is the case, for example, of seed crops such as rapeseed and sunflower. Mostly, the production and rotation cycles of these crops, when produced for non-food purposes, does not differ much from the traditional practices and such crops can be included in rotations with traditional food crops. Therefore, at current and future scenarios, the description of their management in rotation can serve as a general guide for other crops of the same family. On the other hand, as the management of new energy crops is not well developed, research on rotations and crop sequences should be given high priority in order to evaluate their appropriateness and adaptability to fit specific conditions.

Among the large variety of annual, herbaceous perennial, and woody short rotation non-food crops that could be included in energy production systems, annual crops are, in fact, the ones which are intensively managed in rotation systems. Therefore the most prominent 4F annual crops selected in this review, based on their economic significance, geographical distribution, suitability to the climatic conditions, uses, and management practices are:

- Sweet and fiber sorghum (*Sorghum bicolor*);
- Sunflower (*Helianthus annus*);
- Flax (*Linum usitatissimum*);
- Rapeseed (*Brassica napus*);
- Ethiopian mustard (*Brassica carinata*);
- Hemp (*Cannabis sativa*)

The information summarized in the following section focuses on the crop rotation possibilities of the above crops and their viability of been included in a rotation system alongside food crops based on their biological interactions and adaptability to climatic and geographical areas at a macro-regional level. Specific situations are, however, so different that generalized solutions are impossible. Therefore in the long-term the detailed information on management components (e.g. tillage, irrigation, harvest time, available equipment, etc.) and their interactions with the specific conditions of a site, agronomic potential, environmental impact and economics must be generated so dynamic farm-tailored crop
rotations could be developed. The rotation possibilities utilizing perennial herbaceous species and woody crops is not considered here because of the long-term crop rotations required (between 10 to 20 years). Moreover, besides that planning such rotations are not attractive for farmers, the beneficial effects of long crop rotations may become insignificant, if there are any.

**Sorghum** (*Sorghum bicolor*)

In this section sweet and fiber sorghum are discussed together because they belong to the same family and the suggested rotational practices may apply to both species. Sorghum is a highly productive C4 plant native to tropical zones and tolerant to drought. Therefore is best adapted to the Mediterranean climates of southern Europe and drier areas of central Europe. It grows well in areas with a range of precipitations between 300 and 700 mm yr\(^{-1}\), temperatures between 16 and 40 °C and an altitudinal range of 0 to 1100 m a.s.l. (Tuck, et al., 2006). The length of the growing cycle for short growing cycle cultivars is 90 days and for long growing cycle cultivars, more than 130 days. Sorghum has a wide adaptability to different soil types. It can be cultivated both in sandy loam and in clay soils. However, like most crops, it produces best when cultivated in fertile soils (Guiying et al., 2000). Several sorghum hybrids have been developed and improved throughout the years as dedicated crops for the production of lignocellulose, sugar and starch for the generation of bioenergy feedstock (Rooney et al., 2007; Habyarimana et al., 2004).

**Sorghum management in rotation**

A major advantage of sweet and fiber sorghum is that fit well into conventional crop rotations with food crops. Sorghum can be successfully grown following maize or soybean crops. However it should not be grown after a tobacco crop. In New South Wales, Australia, Holland and Herridge (1992) found that cowpea and sunflower were the best predecessor crops in the rotation for sorghum. The increased yields of sorghum were attributed to the higher levels of nitrogen made available by the N-fixing legume or by the reduced N\(_2\) removal by sunflower. Unger (1984) suggested that including sunflower in the rotation allowed to a more complete and deeper depletion of the soil water, even form deeper soil layers than sorghum water extraction layers, indicating that sunflower could be a more efficient user of the soil resources than sorghum due to its greater rooting zone. Then the favorable effect of sunflower on sorghum yield could be partially explained by the different
demands for nutrients. Sunflower, for example, uptakes less phosphates from the soil than sorghum (Sauerborn et al., 2000).

Sweet and fiber sorghum are susceptible to a number of diseases including anthracnose (red stalk rot), fusarium, and maize dwarf mosaic. Since no fungicides are labeled for sorghum, these diseases could be controlled, to a limited degree, by using resistant varieties and by crop rotations with sunflower, cowpea and maize or soybean.

It has been reported that sorghum has inhibitory effects on weeds and following crops, especially when is grown in rotation with wheat (Einhellig and Rasmussen, 1989; Funnell-Harris et al., 2008). Phytotoxic compounds in sorghum stalks and leaves, may contribute to this allelopathic effect. Moreover Funnell-Harris et al. (2008) demonstrated that different sorghum genotypes affect soil microorganism populations in different ways which in turn have variable effects on subsequent crops.

*Suggested rotation possibilities*

As mentioned above one of the most limiting factors for crop growth is the availability of water. Therefore, the following analysis on sorghum rotation possibilities alongside with food crops was based mainly on the crops water use criteria and their biological interactions. The research works on sorghum rotations suggest that wheat – maize – sunflower – sorghum – fallow or alternatively legume (e.g. soybean or other legume, probably cowpea) – maize – sunflower – sorghum rotations are worth of considering for the southern parts of Europe (Table 1). Since there is a greater probability of soil moisture to accumulate after wheat (legume) due to its shallower root system, the additional moisture stored favors maize following wheat. With soil moisture likely to be somewhat depleted after maize, sunflower have shown the potential to extract water and nutrients that have moved to depths beyond the reach of either maize or sorghum which favors sunflower after maize. Sorghum requires the least amount of available moisture to sustain its yield production potential. This suggest that sorghum following sunflower as the last crop before seeding wheat or a fallow period would be the best choice.

This rotation offers the possibility of introducing soil conservation practices such as no-tillage. With the availability of herbicides for the no-tillage practice, maize can be planted into wheat stubble, sorghum into sunflower stubble and wheat into sorghum stubble. Care, however, should be taken with the phytotoxic effect that sunflower stubble has over some crops such as sorghum. Also it should be considered the phytotoxic compounds that some
sorghum genotypes produce and their inhibitory effects on wheat, so probably a fallow period would be recommended after sorghum.

Including a legume such as soybean at the begging of an alternative rotation scheme could be beneficial for the system because legumes drive rotation systems, improve soil conditions and fertility which makes weeds easier to control. Depending on the objectives and particular conditions of a farm or group of farms the aforementioned rotation systems could be adjusted accordingly. A shorter rotation system of wheat (legume) – sunflower – sorghum could also work well in warm climates.

In the hypothetical scenario where the existing infrastructure and organization of a region may require that all the production should be exclusively dedicated to supply feedstock for the bioethanol industry, the crop components included in the rotation should have such potential. In that case, it will be necessary to carefully consider the characteristics of the species included in the rotation, their interactions, growing conditions, and adaptability to the prevailing climatic conditions. In an attempt to do a preliminary exercise on that direction, a maize – sugar beet – sorghum rotation is suggested for warm summer climates (Table 2). Sugar beet could be introduced in a double cropping system with autumn sowing. Rhizoctonia is a major problem for sugar beet production but in general, cereals do not host rhizoctonia root rot fungus and can help to break the disease cycle when included in a rotation. There is, however, controversial information on the disease reduction effect of maize. So growing maize as predecessor crop for sugar beet should be carefully monitored. On the other hand, the rapid growth and consequent rapid soil cover by maize and sorghum, favors their positioning in the rotation as a way to control and reduce annual and perennial weed populations. Moreover, water may accumulate in the soil due to the lower water requirements of sorghum, which favors the growing of maize after sorghum.

**Sunflower (Helianthus annuus)**

Sunflower is a well suited crop for central and southern European regions. Sunflower can be grown within a range of 350 to 1500 mm yr\(^{-1}\) of precipitation, 15 to 39 °C of temperature and a similar altitudinal range to sorghum, hemp and flax (Tuck et al., 2006). The growth period of sunflower varies from 95 to 130 days depending on early or late maturing cultivars. There are two types of cultivated sunflower; the confectionary ones used for human consumption and bird food and, the oilseed ones (Johnston et al., 2002) used for oil production. Sunflower produces seeds with an oil content of 40% or more, however the oil has a high iodine number
(Johnston et al., 2002; Venendaal et al., 1997) but it seems possible to breed for low-iodine varieties (Venendaal et al., 1997).

**Sunflower management in rotation**

Sunflower works well in rotation with food crops such as maize, soybean and sorghum but should not be planted in the same field more than once every three to four years due to the risk of buildup of diseases (Johnston et al., 2002). As a double crop after wheat, sunflower is a good choice as well as soybean in northern zones. Sunflower is shorter season than most crops, so can be planted later or harvested earlier, helping to spread the work load. The deep rooting habit of sunflower allows it to perform well when planted following a shallower rooted crop such as wheat or proso millet (Kansa State University, 2005). Moreover, sunflower is an efficient crop at extracting soil water, therefore the yield of subsequent crops could be reduced, especially in drier zones or years (Nielsen et al., 1999). To reduce the potential of crop failure after sunflower, soil water conservations measures should be taken and drought tolerant crops should be grown after sunflower. Under wet conditions (normal rain distribution, irrigation), however, the effect of sunflower on the subsequent crops is not a factor. In fact, it was found that the yield of crops following sunflower were increased when the soil moisture was adequate (Kansa State University, 2005).

Due to the reduced crop cover left by sunflower the risk of soil erosion is increased especially in areas with fragile soils. Bowman et al. (2000) found that the low amounts of residue after sunflower and the tillage practice used to incorporate herbicides for sunflower production reduced the soil organic carbon and organic matter-carbon and the yield of the subsequent crop (wheat). Therefore it is recommendable to consider a fall cover crop after sunflower and the use of no-tillage or reduced tillage practices to decrease soil erosion and evaporation losses (Johnston et al., 2002; Kansa State University, 2005). Also the no-tillage practice may prevent or reduce the buildup of certain weed species that affect sunflower at early growth stages (Johnston et al., 2002).

Other investigations reported phytotoxic effects of sunflower residues on some summer crops and weeds. Batish et al. (2002) for example indicated that the yield of sorghum, maize, pearl millet and cluster bean were reduced due to the phytotoxic phenolics released from decomposing sunflower residues.

*Suggested rotation possibilities*
A similar crop rotation system as in the case of sorghum may work well for sunflower [wheat – maize – sunflower – sorghum – fallow or wheat (legume) – sunflower – sorghum] because both crops grow well within the same environmental (central and southern Europe) range and share the same food and non-food crop sequencing possibilities (Table 1). Also because the interactions between plants and uptake patterns of soil resource may be similar. However, care should be taken with the phytotoxic effects of sunflower residues. The complete decomposition or removal of sunflower residues before seeding the following crop should be considered carefully.

In the hypothetical case that large areas could be exclusively dedicated to produce oilseed crops and that they will supply the feedstock demanded by a growing bio-oil industry, several oil crops could be used for that purpose. In climates with high summer temperatures and dry periods, however, only few alternative crops could be included in such rotation systems. Therefore, the suggested rotation could be: soybean – Ethiopian mustard – sunflower (Table 2). Although soybean is not include in the set-aside land in Europe, its high protein-oilseed production potential warrants its inclusion in a bioenergy crop rotation system of such characteristics. A major problem, however, with this rotation is that the three species are carriers and somewhat susceptible to sclerotinia. The use of certified seeds and resistant hybrids may help, to some extent, to control the disease. Besides that the drier environmental conditions where this rotation probably will be implemented, also favors to the limited progression of the disease. But when sclerotinia appears, rotations to nonsusceptible crops such as small grains, maize and sorghum are necessary. Because the agronomic practices for Ethiopian mustard and rapeseed are similar, and possibly their nutrient requirements, the nitrogen fixed by the preceding soybean could be beneficial for Ethiopian mustard as it is for rapeseed. Furthermore, including Ethiopian mustard in the rotation may reduce chemical use, increase profits and increase crop diversity in dryland areas. Sunflower is a deep rooted crop and efficient user of soil resources which favors its growth at the end of the rotation.

**Rapeseed** (*Brassica napus*)

Rapeseed, the most widely grown energy crop across Europe, belongs to the cruciferous family. Improvements through plant breeding in the fatty acid composition of the oil and glucosinolates in the meal made rapeseed one of the world most important oil crops after soybean and palm (Johnston et al., 2002). It is mainly grown in temperature climates of central Europe and parts of southern and northern Europe. Winter rapeseed is the dominant
oilseed crop in northern Europe, often grown in short rotations with food crops such as barley and wheat (Rathke et al., 2005). It grows in areas with a range of 400 to 1500 mm yr\(^{-1}\) of precipitation and 6 to 40 °C of temperature. Rapeseed can be grown from 0 to 800 m.a.s.l. (Tuck et al., 2006). Rapeseed maturity varies considerably depending on location, growing season, and date of seeding, it could take from 70 to 130 days to complete its life cycle. The production of rapeseed for non-food purposes include oils for the biodiesel and biolubricant industry (Venendaal et al., 1997). The crop is consider a high input crop as it requires high N fertilization and has low resistance to pests (Venendaal et al., 1997).

**Rapeseed management in rotation**

Rapeseed can be introduced in a wheat rotational system with positive effects on the cereal yield. The main effects of including rapeseed in a rotation are due to better management of weeds and diseases (e.g. septoria and tan spot; Johnston et al., 2002). The reduction in cereal diseases arises because rapeseed is not a host of cereal diseases and thus their populations tend to decline (Canola council of Canada, 2009). On the other hand, the yields of rapeseed can also be improved when grown in rotation with cereals. The yield benefits are more consistent when rapeseed is grown in a 1-in-3 years or 1-in-4 years rotation. The longer the rotation the lower the nitrogen fertilization costs and the lower the insect/pathogen pest infestations (Cathcart et al., 2006). Moreover, the rotation of rapeseed with cereals makes the system more efficient in terms of water use due to the different rooting depths and lower water requirements of rapeseed than cereals (Canola council of Canada, 2009). Even though the yield of rapeseed is increased following a cereal crop, several investigations showed that rapeseed yields were even significantly higher after pea, probably due to the supplied nitrogen by the legume that is highly demanded by rapeseed (Rathke et al., 2005). But the crop sequence of cereal - rapeseed is not always beneficial as indicated by an Australian research work that found that different wheat varieties have variable degrees of phytotoxic effects on rapeseed germination and growth (Bruce et al. 1999). Growing rapeseed on its own stubble is not beneficial either, because promotes disease and insect buildup. Yield reductions can also occur when rapeseed is grown on other crops stubble susceptible to the same pests such as flax, mustard, sweet clover, soybean, field beans, lentils and sunflower (Canola council of Canada, 2009).

Including rapeseed in frequent (short) rotations may negatively impact beneficial organism populations such as rhizobia and vesicular-arbuscular mycorrhizal fungi (VAM)
and their symbiotic relationships with the subsequent crops (Krupinsky et al., 2002; Canola council of Canada, 2009).

The risk of water and soil erosion increases after rapeseed due to its characteristic low residue production and faster decomposition than cereals residues, especially when is followed by summer fallow (Canola council of Canada, 2009). The inclusion of a summer cover crop (legume) in the rotation may help to reduce problems related soil erosion.

**Suggested rotation possibilities**

The research works on rapeseed rotation suggest that a rapeseed – cereal (e.g. wheat, barley, oat) – cereal – rapeseed rotation could be an important option to explore in temperate climates (Table 1). Since the root systems of both species are structurally different and rapeseed has lower water requirements than the cereals such combination makes the system more efficient in terms of utilization of soil resources. Moreover, rapeseed is a high input crop and the use of residual N by a subsequent crop could also improve its yield and the profitability of the system. Besides that, cereals and rapeseed do not have common diseases, therefore growing a cereal before or after rapeseed favors the control of diseases in both crops. This crop rotation also favors the introduction of reduced tillage practices with their consequent beneficial agronomical and environmental effects. The introduction of a legume into the rotation could further improve the performance of the system; the suggested crop sequence could be pea – rapeseed – cereal – cereal. Moreover a summer cover or cash crop, in a double cropping system, may improve the profitability of the rotation.

In a rotational system that would exclusive provide feedstock for a bio-oil industry the suggested tentative rotation could be rapeseed – flax – safflower (Table 2). To reduce the potential phytotoxic effects of rapeseed over flax, it would be recommendable to spread uniformly the rapeseed residues or seed flax into untilled rapeseed stubble. On the other hand, since rapeseed is a high input crop, the residual nutrients, specially phosphorus, may favor the growth of flax after rapeseed. Relative to the other oilseed crops, flax has the shallowest root system, therefore water and nutrients are likely to accumulate in deep layers. Therefore, the deep rooting system of safflower, grown after flax, may take advantage of the accumulated resources.

**Flax** (*Linum usitatissimum*)
Flax is an ancient crop belonging to the family Linaceae. Mainly two types of flax are cultivated: for seed oil and fiber production (Johnston et al., 2002). The two types have many uses including industrial oils from oilseed flax, food-quality flaxseed oil, linen products, fiberboard and paper products from straw. Flax is a temperate climate crop that grows well across most of Europe including Northern Scandinavia. The temperature range for flax growth varies from 4 to 32 °C and the precipitation range from 250 to 1300 mm yr\(^{-1}\) at altitudes going from sea level to 900 m.a.s.l. (Tuck et al., 2006). Flax growth period is 115 - 120 days and responds well to early seeding.

**Flax management in rotation**

Although flax is an ancient crop few rotational studies have included it. It is recommended that flax should be grown in 3-year rotations to avoid the buildup of soil-borne and stubble borne diseases of flax (Flax council of Canada, 1998). In a study on the Canadian prairies, Campbell and Zentner (1996) found that compared to wheat, flax conserve soil NO\(_3\) and water below 60 cm depth, probably due to its shallow rooting habit. Other studies suggested that growing flax after wheat may help to strengthen the symbiotic relation with mycorrhiza and uptake of phosphorous (Grant et al., 2004; Johnston et al., 2004) but not after rapeseed which is a non-mycorrhizal crop.

It is reported that flax sometimes does poorly after rapeseed and mustard due to toxic compounds in rapeseed and mustard residues (Grant et al., 2004). This is more evident when the stubble of the previous *Brassica* crops are not well spread on the soil. It has been also recommended that flax should not be grown after potato, legumes or sugar beets (Flax council of Canada, 1998) as the soil could be too loose leading to Rhizoctonia problems. However Johnston et al. (2004) reported an increase of 20 % on flax yield when seeded on pea stubble.

Flax is a poor stubble producer which in turns results in dryer and warmer soil surfaces than under wheat stubble, therefore selection of drought tolerant crops following flax in hot and drought prone areas is recommended (Johnston et al., 2002, 2004). The flax council of Canada (1998) indicated that flax does well after cereals, maize, legumes and alfalfa while wheat and barley does well after flax.

*Suggested rotation possibilities*
Due to the limited information on rotation systems including flax, this preliminary analysis suggests that a rotation flax – wheat – legume could be beneficial because of the spatial complementarity in soil resource used by flax and wheat (Table 1). Since there is a greater probability of soil moisture and nitrogen to accumulate in deep soils after flax due to its shallower root system, the additional soil resources stored in deeper layers favors wheat following flax. As mentioned above, the inclusion of legumes into a rotation is always beneficial as they improve soil conditions and fertility. However more information is required in order to more precisely determine the plant interrelations and their effects in crop rotations including flax.

**Hemp (Cannabis sativa)**

Hemp has a long history as a fiber crop, but the energetic use of hemp is a relatively new concept. For the energetic purposes, harvesting of the whole plant is required (Venendaal et al., 1997). The yield of hemp, however, is affected by environmental conditions and agronomic practices (Struik et al. 2000). Hemp is ideally suited to mild temperate climates, and is mostly grown in central Europe and some areas of northern and southern Europe. Hemp can be grown in areas with precipitations between 600 and 1500 mm yr\(^{-1}\), temperatures between 5 and 28 °C and altitudes from 0 to 950 m.a.s.l. (Tuck et al., 2006). Hemp fibers can be used as straw and hurds material, and energy production, while the oils from hemp can be used for food, cosmetics or the pharmaceutical industry (Ranalli and Venturi, 2004).

**Hemp management in rotation**

Only few studies have dealt with the effects of hemp in a rotation system. As an annual crop hemp fits well into crop rotation where it may serve to the control pests as it is not related to conventional food crop species (Venendaal et al., 1997). Moreover, the high planting density of hemp may help to control weeds.

According to Grochs et al. (2000), who studied the effects of hemp in a rotation with wheat in the humid cool areas of North-eastern Spain, hemp is a good precedent crop for wheat probably because of the leaf cover left and the increased soil aggregate stability. The rotation effect was expressed in the increased yield of wheat and it extended until the second year of wheat after hemp and disappeared in the third year after hemp. The deep rooting ability of hemp (Amaducci et al., 2008) could also be another beneficial factor in rotations with shallower rooted crops such as wheat.
Another study indicated that hemp can be used in rotation as a nematicide with crops susceptible to nematode attacks such as potatoes, maize, peas, grains and pastures. The suggested bio-pesticide effect of hemp is based on the findings that only few nematodes infests its roots and hemp plant extracts produce potent nematicidal agents (McPartland and Glass, 2001).

Suggested rotation possibilities
The almost complete lack of information on rotational possibilities including hemp suggest that much research work has to be done before a crop rotation system could be establish as a reference for farmers across different environments. The limited studies on hemp rotations, however, suggest that hemp – wheat rotation works well in temperate climates, but longer rotations including other food and non-food crops should be tested.

Conclusion
Even though the rotation systems for sorghum, sunflower and rapeseed have not been specifically developed for their non-food production purposes, the management practices and rotation cycles do not differ much from the traditional food cropping practices. Therefore, the rotational management practices described here can serve as a general guide and could be also applicable for other food and non-food crops of the same family. On the other hand, the rotational management of new energy crops such as Ethiopian mustard and fiber sorghum is not well developed, therefore research on rotations possibilities and crop sequences should be given high priority.

In the southern parts of Europe the best rotation choice that would optimize the utilization of soil resources and fit the prevailing climatic conditions would be wheat (legume) – maize – sunflower – sorghum – fallow (Table 1). As for temperate climates (northern Europe) rapeseed – cereal (e.g. wheat, barley, oat) – cereal – rapeseed rotation would be the best choice (Table 1). Moreover, the preliminary information analyzed here suggests that a rotation including flax – wheat – legume could be also beneficial for these regions (Table 1).

The great potential of hemp to be included in crop rotations, as it is not related to conventional food or non-food crop species, should be further developed.
In the hypothetical scenario where all the crops included in a rotational system are dedicated to the production of feedstock for bioenergy purposes, the tentative suggested rotation systems are summarized in table 2.

Table 1. Climatic regions and rotation possibilities

<table>
<thead>
<tr>
<th>Environmental zones</th>
<th>Suggested crop rotations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nemoral</td>
<td>Rapeseed – Cereal (wheat, barley, oat) – Cereal – Rapeseed</td>
</tr>
<tr>
<td>Continental</td>
<td>Wheat (legume) – Maize – Sunflower – Sorghum – fallow</td>
</tr>
<tr>
<td></td>
<td>Flax – Wheat – Legume</td>
</tr>
<tr>
<td>Atlantic central</td>
<td>Rapeseed – Cereal (wheat, barley, oat) – Cereal – Rapeseed</td>
</tr>
<tr>
<td></td>
<td>Flax – Wheat – Legume</td>
</tr>
<tr>
<td>Atlantic north</td>
<td>Rapeseed – Cereal (wheat, barley, oat) – Cereal – Rapeseed</td>
</tr>
<tr>
<td></td>
<td>Flax – Wheat – Legume</td>
</tr>
<tr>
<td>Lusitanian</td>
<td>Wheat (legume) – Maize – Sunflower – Sorghum – fallow</td>
</tr>
<tr>
<td></td>
<td>Rapeseed – Cereal (wheat, barley, oat) – Cereal – Rapeseed</td>
</tr>
<tr>
<td>Mediterranean North</td>
<td>Wheat (legume) – Maize – Sunflower – Sorghum – fallow</td>
</tr>
<tr>
<td></td>
<td>Flax – Wheat – Legume</td>
</tr>
<tr>
<td>Mediterranean South</td>
<td>Wheat (legume) – Maize – Sunflower – Sorghum – fallow</td>
</tr>
<tr>
<td></td>
<td>Flax – Wheat – Legume</td>
</tr>
</tbody>
</table>

Table 2. Climatic regions and rotation possibilities in an hypothetical scenario where all crops are exclusively dedicated to the production of feedstock for bioenergy purposes.

<table>
<thead>
<tr>
<th>Environmental zones</th>
<th>Hypothetical suggested crop rotations</th>
<th>Feedstock supplied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nemoral</td>
<td>Rapeseed – Flax – Safflower</td>
<td>Bio-oils</td>
</tr>
<tr>
<td>Continental</td>
<td>Maize – Sugar beet – Sorghum</td>
<td>Ethanol</td>
</tr>
<tr>
<td></td>
<td>Rapeseed – Flax – Safflower</td>
<td>Bio-oils</td>
</tr>
<tr>
<td>Atlantic central</td>
<td>Rapeseed – Flax – Safflower</td>
<td>Bio-oils</td>
</tr>
<tr>
<td>Atlantic north</td>
<td>Rapeseed – Flax – Safflower</td>
<td>Bio-oils</td>
</tr>
<tr>
<td>Lusitanian</td>
<td>Maize – Sugar beet – Sorghum</td>
<td>Ethanol</td>
</tr>
<tr>
<td>Mediterranean North</td>
<td>Soybean – Ethiopian mustard – Sunflower</td>
<td>Bio-oils</td>
</tr>
<tr>
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</tr>
<tr>
<td></td>
<td>Rapeseed – Flax – Safflower</td>
<td>Bio-oils</td>
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<td>Maize – Sugar beet – Sorghum</td>
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<td>Soybean – Ethiopian mustard – Sunflower</td>
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</table>

* Some crops such as maize and sugar beet may require supplemental irrigation.

**References**


